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Recycling Urban Stormwater for Profit

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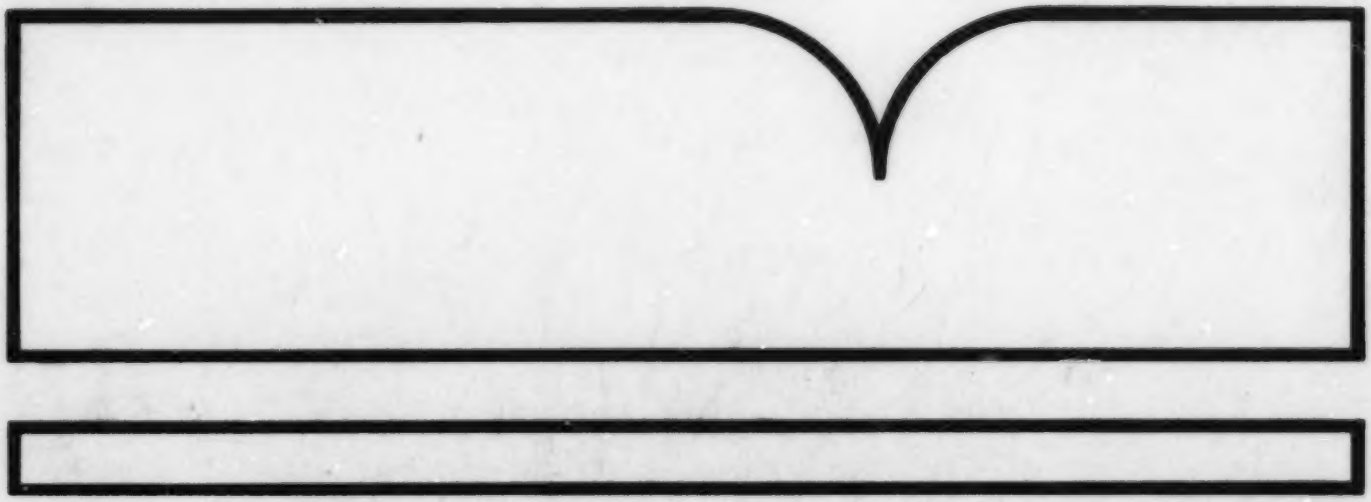

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16. ABSTRACT

Rainfall runoff becomes contaminated as it passes over urban land. Billions of gallons of water can be recovered for beneficial uses if urban stormwater is properly controlled and treated. The Storm and Combined Sewer Program of the United States Environmental Protection Agency Office of Research and Development has continuously supported the development and demonstration of stormwater control systems and treatment processes. Water quality of the treated storm runoff can meet the required standards for subpotable usage. Current urban stormwater control and treatment technology are discussed, leading to the feasibility of urban stormwater reuse for various purposes in industry, irrigation and recreation. A hypothetical case study illustrating the cost effectiveness of reclaiming urban stormwater for complete industrial supply is presented.

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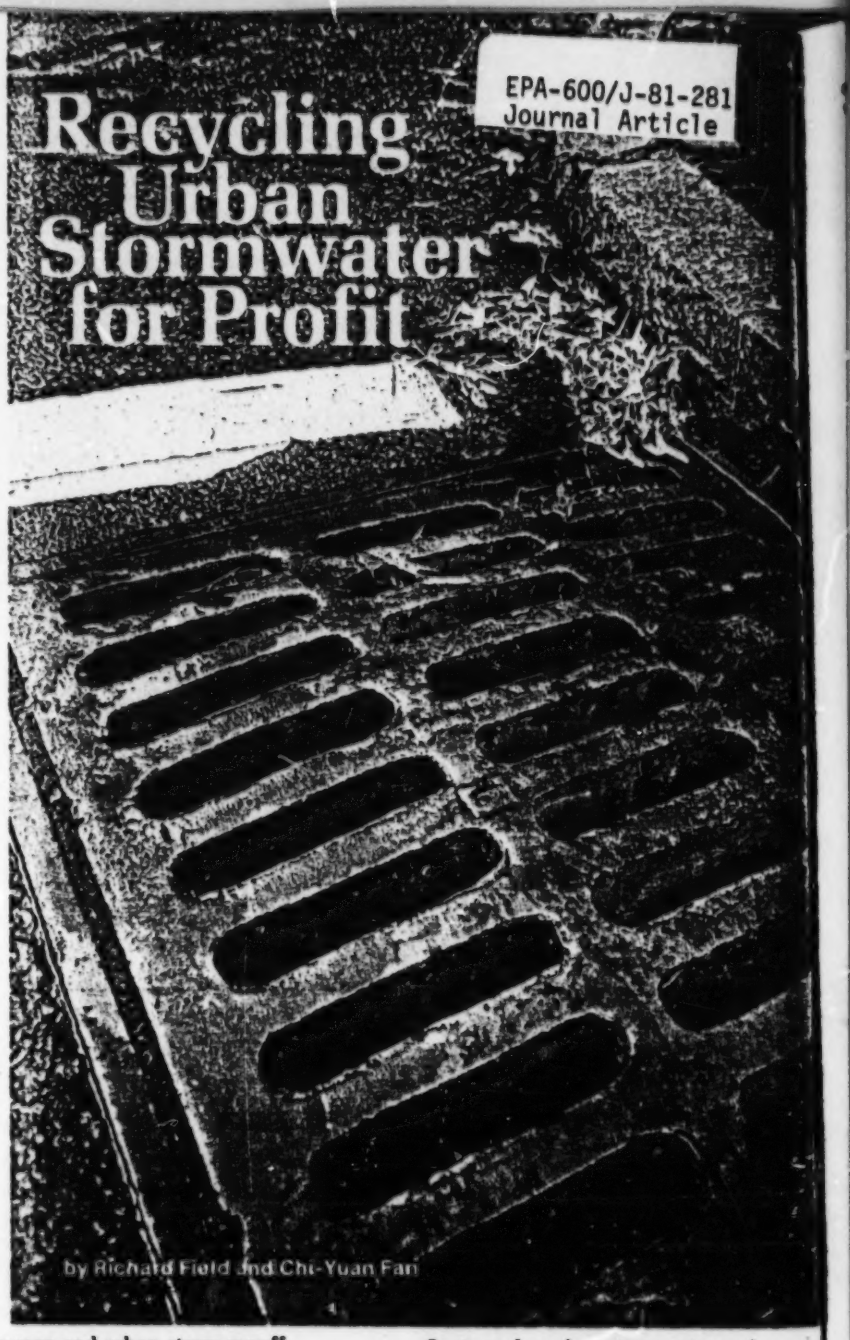

Photo courtesy William Bird/Camp Dresser & McKee

by Richard Field and Chi-Yuan Fan

As population and industry grow, water demand increases and the problem of supplying water grows. It has been estimated that the total gross water intake for all purposes in the U.S. will exceed the total available water supply of 650 BGD by the year 2000. Therefore, wastewater reclamation will become more significant as a means of augmenting water supply.

Reclamation of municipal wastewater for industry, nonpotable domestic usages, and groundwater recharge has been practiced in the U.S. for the past several decades. In a 1971 EPA-supported nationwide survey, it was estimated that current reuse of treated municipal wastewater for industrial water supply, irrigation, and groundwater recharge was 53.5, 77, and 12 BG/yr, respectively.[1] It is reasonable to expect that the reuse of the treated wastewater for industrial cooling, nonpotable domestic water supply, and park and golf course irrigation will be increased in the future.

Publications are available on the reuse of municipal effluent for potable and nonpotable water supply.[2-4]

Very limited information is available, however, on reuse and reclamation of urban stormwater. This paper discusses current urban stormwater control and treatment technology leading to the feasibility of urban stormwater reuse for various purposes including industrial cooling and process, irrigation, and recreational water supply. The hydrologic and hydraulic aspects of urban stormwater systems are presented elsewhere and are not addressed here. A hypothetical case study illustrating the cost-effectiveness of reclaiming urban stormwater for complete industrial supply is presented.

Urban stormwater and combined sewer overflows. In recent years a considerable number of characterization studies have been performed on urban stormwater.[5] The reported stormwater pollutant concentrations and flowrates vary considerably with time and location during a storm and from one storm to another. The data indicate that the BOD_5 concentration is very close to that of the municipal sewage secondary treatment plant effluent, while the suspended solids concentration is similar to that of raw sanitary wastewater.

Combined sewer overflow (CSO) is a mixture of various proportions of municipal sewage and storm runoff. For this reason, it would seem that the pollutant concentration of CSO would lie between that of the local sanitary sewage and urban storm runoff.

Control and treatment processes. Many unit processes designed for treatment of water and wastewater can be adapted to stormwater treatment. Because of the high volume and variability associated with storm and CSO, high-rate physical treatment units are considered to be advantageous over biological systems in many situations. Physical treatment alternatives have demonstrated the capability to handle high and variable flowrates and solids concentrations, whereas biological processes are more vulnerable to these variable flow conditions and the relatively high concentration of nonbiodegradable solids in storm flow. Therefore, physical systems are emphasized here.

Systems for urban stormwater reclamation may include storage and pretreatment, secondary treatment, and advanced treatment processes. Selection of treatment level is dependent on the reclaimed water usage. For example, water supply for irrigation requires a minimum degree of treatment, while that for boiler feed requires a high level treatment. The various units for these basic processes are:

- Control - storage or retention basin and swirl regulator/concentrator;
- Pretreatment - bar/coarse screen; swirl concentrator and sedimentation;
- Secondary treatment - fine mesh screening, sedimentation, dissolved air flotation and/or microscreening with biological treatment;
- Advanced treatment - combination

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of screening, filtration, carbon adsorption.

These processes have been successfully demonstrated and evaluated by EPA's ORD Urban Stormwater Control Technology Program.[5-21]

Stormwater reclamation. The basic treatment and control methods indicated above have been evaluated essentially as singular processes, but system optimization should be considered to enhance overall treatment effectiveness and stormwater reuse potential. Integrated treatment systems may be used to produce four effluent levels for differing water quality classifications. A typical flow diagram for several advanced physical-chemical treatment systems is shown in **Fig. 1**. Each treatment system produces a different degree of effluent water quality, except for sedimentation and fine screening/high-rate filtration, which result in similar treatment efficiencies. The flow diagram also indicates the water quality classifications associated with different water uses. Class "AA" is intended for high quality application such as steam generation boiler feed. Class "A" is intended for routine industrial process supply and has lower dissolved mineral removal requirements than Class "AA." Class "B" may be used for industrial cooling and recreational water for fishing. Additional nutrient removal may be warranted. Finally, Class "C" is intended for lawn irrigation, fire protection and aesthetic ponds.

Table 1[22] indicates maximum concentrations of selected quality parameters. The water demands for each use must be evaluated with respect to the four water quality levels described above and defined in **Table 1**. Specific unit process selection and system design should only be determined after suitable investigation of the quality and quantity characteristics of the stormwater at the site and laboratory/pilot-scale evaluations.

Hypothetical Case Study.

A case study for a hypothetical industrial complex is presented to illustrate an engineering economic analysis of urban stormwater reclamation. Three water quality classification levels (A, B and C as shown in **Table 1**) were used to represent a range of industrial application. Three water supply source combinations including reclaimed urban stormwater and/or city water were considered as potential alternatives for the case study:

Alt. 1. Use of *city water* for all applications: law irrigation, potable, cooling make-up, and process supply.

Alt. 2. Use of *reclaimed stormwater* for lawn irrigation, cooling make-up, process supply, and *city water* for potable supply.

Alt. 3. Use of *reclaimed stormwater*

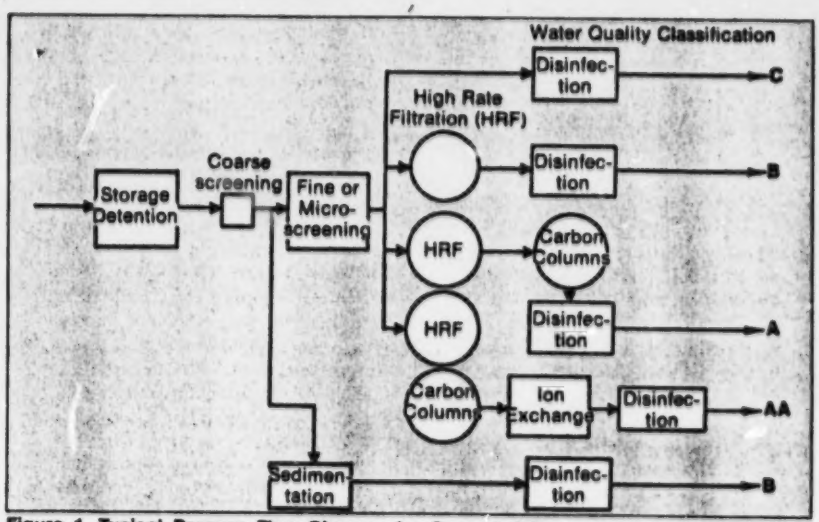

Figure 1. Typical Process Flow Diagram for Several Advanced Physical/Chemical Treatment Systems.

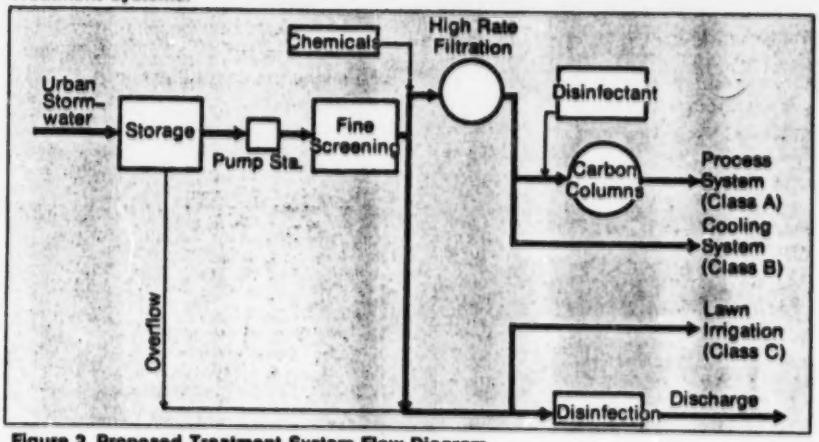

Figure 2. Proposed Treatment System Flow Diagram.

Table 1
Maximum Concentration of Selected Pollutant by Reuse Category[22]

Constituent (mg/l unless indicated)	Required Water Quality* Maximum Concentration			
Water Quality Classification	**AA**	**A**	**B**	**C**
Ammonia (NH_3)	0.5	0.5	0.5	0.5
Arsenic	0.01	0.05	0.05	0.05
Calcium	0.5	75.0	75.0	75.0
Chloride	50.0	250.0	250.0	250.0
Chromium (hexavalent)	0.05	0.05	0.05	0.05
Copper	1.0	1.0	1.5	1.5
Cyanide	0.01	0.2	0.2	0.2
Fluoride	1.5	3.0	3.0	3.0
Iron	0.1	0.3	0.3	0.3
Lead	0.05	0.1	0.1	0.1
Magnesium	0.5	150.0	150.0	150.0
Manganese	0.05	0.1	0.5	0.5
Nitrate (as NO_3)	45.0	50.0	50.0	50.0
Oxygen, dissolved (minimum)	5.0	5.0	4.0	4.0
Sulfate	50.0	200.0	400.0	400.0
Total solids	150.0	500.0	500.0	1,500.0
Zinc	5.0	15.0	15.0	15.0
Coliform (MPN per 100 ml)	1	70	240	240
pH (units)	7.0	6.0	6.0	6.0
Color (units)	15	20	30	30
Turbidity (units)	0-3	3-8	8-15	15-20
Suspended solids	—	—	10.0**	30.0**
Phosphates	1.0	1.0	1.0	1.0

**Based upon maximum concentrations allowed by the USPHS, the World Health Organization, and the Water Quality Standards of the state of Maryland.*

***Higher suspended solids are permitted by various water quality standards. Limit based on sediment control and water contact recreation.*

for lawn irrigation and cooling make-up, and *city water* for potable and process supply.

The industrial complex is being established on a 100 acre tract of which 25 percent is used for open lawn and 75 percent for buildings, facilities, and roadways. Overall demand for water at the industrial site in the case study is expected to be about 8.0 mgd based on assumed population (10,000 persons), lawn irrigation (4 in. per week and 8 months per year), and in-plant cooling and processes. An additional intermittent demand of 9.11 mgd for storage basin overflow disinfection was estimated based on long-term hydrological analysis. **Table 2** summarizes the water demands and water quality classifications. **Table 3** presents typical water quality requirements for cooling tower make-up and process supply and these are assumed to be the hypothetical case study requirements:

Stormwater reclamation system. The stormwater reclamation system includes a storage reservoir and treatment facilities. The basic purpose of the system is industrial water supply, but the system also provides the multi-benefits of enhanced drainage control, water pollution abatement, and improved local aesthetics. In other words, the storage basin functions as a water supply reservoir, flow attenuator, pollutant load attentuator or separator, and an aesthetic pond. For pollution control, the reservoir should be designed and operated to prevent degradation of downstream receiving water quality. For water supply, the design criteria are industrial water demand rate, storage capacity, and the reliability with which the demand can be satisfied.

In studying storage requirements for the case study, the basin drainage locations (or catchment areas) were first analyzed to determine the industrial plant yields versus volume/capacity relationships assuming 100 percent reliability over a representative five-year build-up period of stormwater inflow volume. A mass flow accumulation diagram (volumetric flow accumulation over a long time) with the known industrial process demand rate was used for this purpose.

Next, effluent water quality was analyzed in terms of system design and operating requirements. Finally, treatment process design criteria and capacities were developed which met all three plant water use (water classes A, B and C) requirements. Detailed methodology and procedures for hydrological and process analyses are discussed in other publications.[5,7,22,23]

Fine-mesh screening has had relatively wide use for storm flow treatment for both the main process and for pretreatment in such processes as high-rate filtration and dissolved air flotation.[5,7,15] High-rate filters hold promise for stormwater treatment based on large-scale pilot demonstrations.[5,7,16,24] Carbon adsorption is usually employed as a tertiary polishing step if a higher water quality is desired and also has a demonstrated ability to treat stormwater.[5,18] The proposed treatment system contains these processes and is depicted by **Fig. 2**. The design flows and criteria of the unit processes are contained in **Table 4**.

Cost analysis. The design criteria listed above were used to size the various units needed for the proposed treatment process, and then the capital and operating and maintenance (O&M)

Table 2
Water Demands and Quality Classifications
(A Hypothetical Case Study)

Use Category	Water Demand mgd	Water Demand mg/year	Water Quality Classification
Lawn irrigation	0.39	94.0	C
Cooling make-up	5.0	1,500.0	B
Potable	0.89	267.0	City water
Process	1.61	483.0	A
Overflow disinfection	9.11	20.0	C

Table 3
Water Quality Requirements
(A Hypothetical Case Study)

Parameter (mg/l)	Cooling Make-Up	Process Supply
Total dissolved solids	1,500	500
Suspended solids	25-100	10
*pH	6.9-7.5	7
**Turbidity	20	5
Calcium	50	50
Iron	0.5	0.3
BOD	25	2.0
COD	75	5
Sulfate	200	50

**In pH units.*
***In Jackson turbidity units.*

Table 4
Design Criteria for Storage-Treatment Facilities
(A Hypothetical Case Study)

Unit Flow Control/Treatment	Design Flowrate mgd	Design Flowrate gpm	Design Criteria
Storage basin	200		30 days
High-rate disinfection units	10	7,000	15 min (contact)
Class "C, B, & A"			
Pumping station	7.2	5,000	—
Fine mesh screens	7.2	5,000	50 gpm/sq ft (influx)
Class "B & A"			
High-rate filters	6.6	4,630	16 gpm/sq ft (influx)
Class "A"			
Carbon columns	1.6	1,130	5 gpm/sq ft (influx) 30 min (detention)

Table 5
Capital and Annual Costs for Urban Stormwater Treatment
(A Hypothetical Case Study)*

Process/Equipment	Capital Cost ($)	Annual Cost ($) Amortization**	Annual Cost ($) O&M	Annual Cost ($) Total
Flow Control Treatment				
Storage basin	3,600,000	396,000	10,000	406,000
High-rate disinfection units	166,000	18,000	117,000	135,000
Class "C, B, & A"				
Pump station	975,000	107,000	90,000	197,000
Fine screening units	208,000	23,000	25,000	48,000
Class "B & A"				
High-rate filtration units	1,200,000	132,000	36,000	168,000
Chemical feed equipment & building	224,000	25,000	100,000	125,000
Class "A"				
Carbon columns	1,300,000	143,000	90,000	233,000
Disinfectant feed system	120,000	13,000	100,000	113,000

**Unit cost.*[21]
***n = 25 yr; i = 10 percent.*

costs were estimated for the various alternatives. The capital costs include: (1) structures, equipment, pumps, and piping; (2) engineering services, legal and administrative (estimated 20 percent of equipment and installation); and (3) land costs ($30,000 per acre).

The capital costs were adjusted using the national average EPAWQO-Sewage Treatment Plant Index of 303.1 (June 1978).

Annual costs were based on a 25-year amortization period at ten percent interest and 300 days per year of plant operation.

The proposed storage reservoir is of lined earthen construction and is 18 ft deep with a 2.5:1 interior slope, a 3:1 exterior slope, and a 16-ft. top width of levee. The reservoir is aesthetically designed to harmonize with the local environment. **Table 5** summarizes the capital, O&M, and total annual costs for the proposed stormwater reclamation treatment facilities using unit costs from Benjes' manual.[25]

Table 6 presents the summary of total annual costs of water supply for each alternative.

Based on the above analysis Alt. 3, utilizing a combination of storm and city water supply, offers a clear savings of approximately $900,000 per year over Alt. 1, utilizing city water only. Even Alt. 2, which is mainly dependent on stormwater supply is $800,000 per year less than the exclusive city water supply alternative. Further savings are realized when the multi-purposes of pollution control, drainage, and aesthetics are considered.

Conclusions. This hypothetical case study provides evidence that the reclamation of urban stormwater for industrial subpotable water supply is technically feasible and economically attractive when compared to the city water source. In addition, other important benefits, such as reduction of pollutant discharges, drainage control, creation of recreational and aesthetic ponds, groundwater recharge, and improvements and preservation of ecology in urban areas will be achieved. ■

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Table 6
Estimated Total Annual Costs of Water Supply
(A Hypothetical Case Study)

Alternative	Purpose	Source	Annual Flow (mg)	Unit Cost ($/1,000 gal)	Annual Costs ($)
1	Irrigation	City Water	94.0	0.80*	75,000
	Cooling	City Water	1,500.0	1.05**	1,575,000
	Process	City Water	483.0	1.20**	580,000
	Potable	City Water	267.0	0.80*	214,000
				Alternative 1—Total	**2,440,000**
2	Irrigation	Class C (Stormwater)	94.0	0.34	32,000
	Cooling	Class B (Stormwater)	1,500.0	0.48	720,000
	Process	Class A (Stormwater)	483.0	1.44	696,000
	Potable	City Water	257.0	0.80*	214,000
				Alternative 2—Total	**1,662,000**
3	Irrigation	Class C (Stormwater)	94.0	0.34	32,000
	Cooling	Class B (Stormwater)	1,500.0	0.48	720,000
	Process	City Water	483.0	1.20**	580,000
	Potable	City Water	267.0	0.80*	214,000
				Alternative 3—Total	**1,546,000**

** Average water consumption charge rate in Middlesex County, New Jersey (June, 1978).*
*** Additional treatment required for control of biological growth, corrosion, and/or scaling.*